Effects of surface waves on SSH … results from theories and models

and roughness for interpretation of SSH signals

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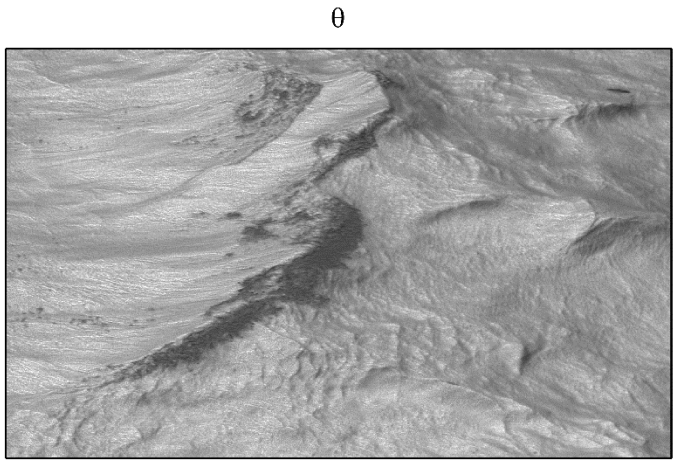
With precious help from S. Gille, D. Menemenlis, J. Gula & C. Rocha

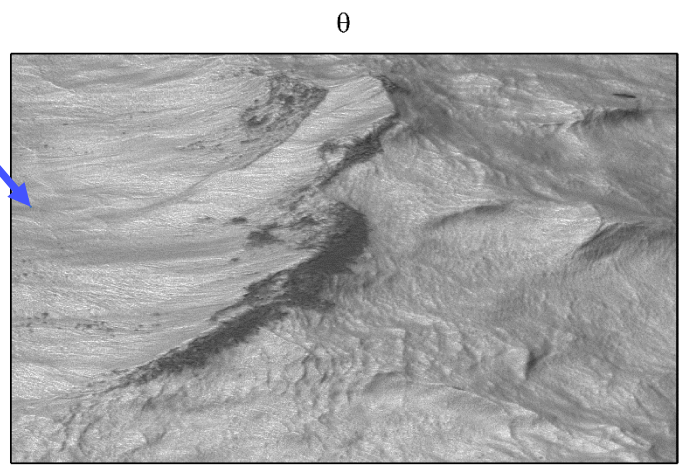
a story of known knowns, known unknowns and … ?



1. Geometric sea state bias

Several effects lead to an apparent mean sea level different from the truth :

- 1. More power is returned from **horizontal** facets… these are **lower**
- 2. SAR-induced displacements
  (see Rodriguez et al. recent efforts)



Here we focus on first effect. Same as nadir altimeters

A rule of thumb is that **SSB ~ b Hs** … with **b ~ 0.03**.

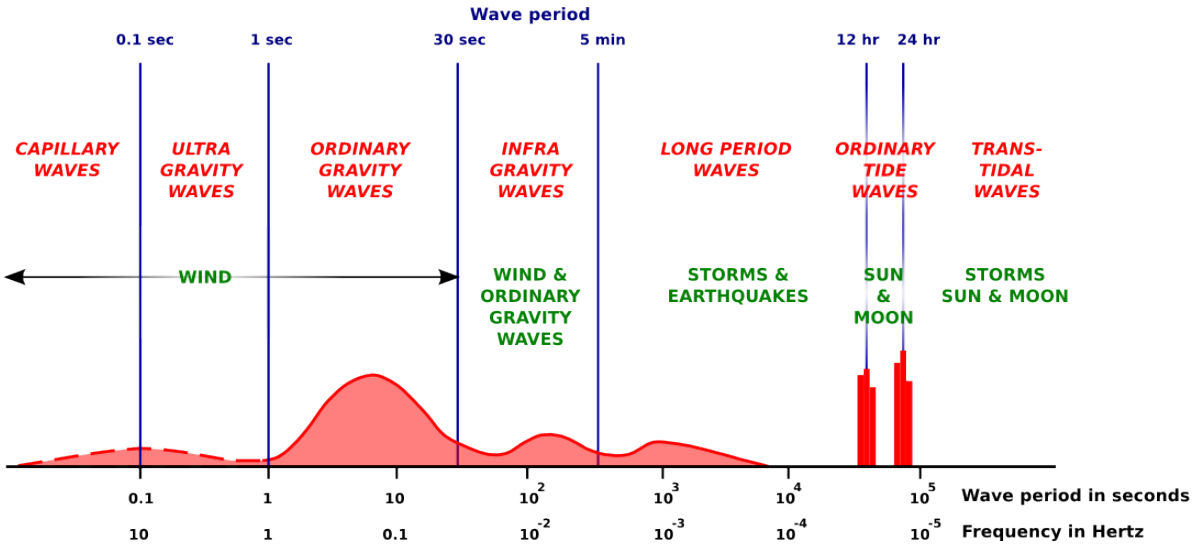
Why Hs ? Because it is commonly measured…

Is b constant ? **No, b is only constant if the wave slopes are constant**

- **(scaling of wave surface geometry)…**

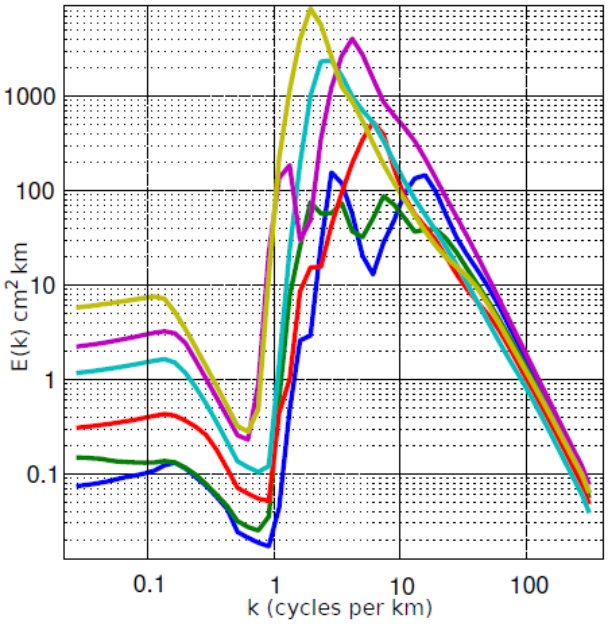
→ we need to measure Hs for SSH estimates.

1. Direct wave elevation at ~ 15 km
Infragravity waves



1.5 m 150 m **15 km** 200 km Wavelength

With SWOT : new issue for altimetry



1 cm² /(cyc / km) exceeded 10% of time off mid-latitude west coasts.

Ardhuin et al. 2014

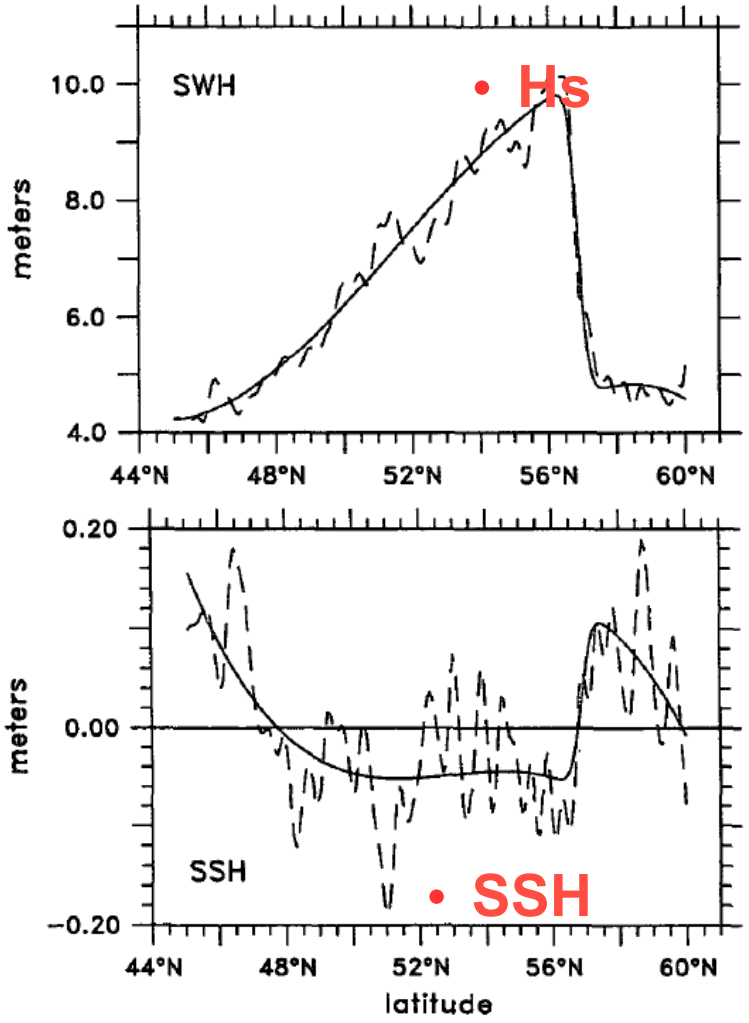
Rawat & al. GRL 2014

1. Geometric sea state bias

First : how fast does Hs varie spatially ?
Second : is b having strong spatial gradients too ?

Back to Minster et al. (1992) :

(see also Fu & Glazman …
up to Tran et al. 2010)



1. Geometric sea state bias
Small scale gradients of Hs

First : how fast does Hs varie spatially ?

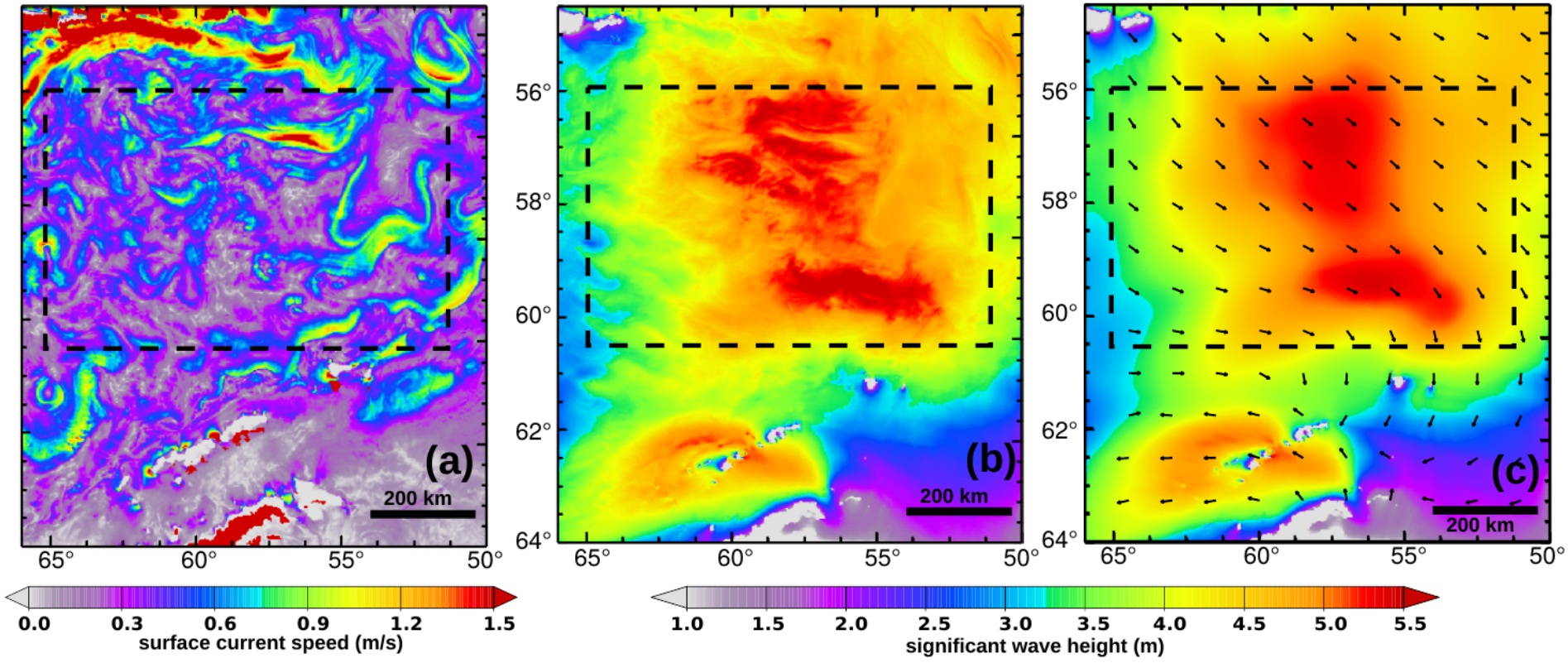
New result : small scale gradients of Hs are due to currents !

(Ardhuin et al., in prep., using same wave model as Ardhuin et al. JPO 2012)

Current from MITgcm

Hs from WW3 using current

Hs from WW3 : no current



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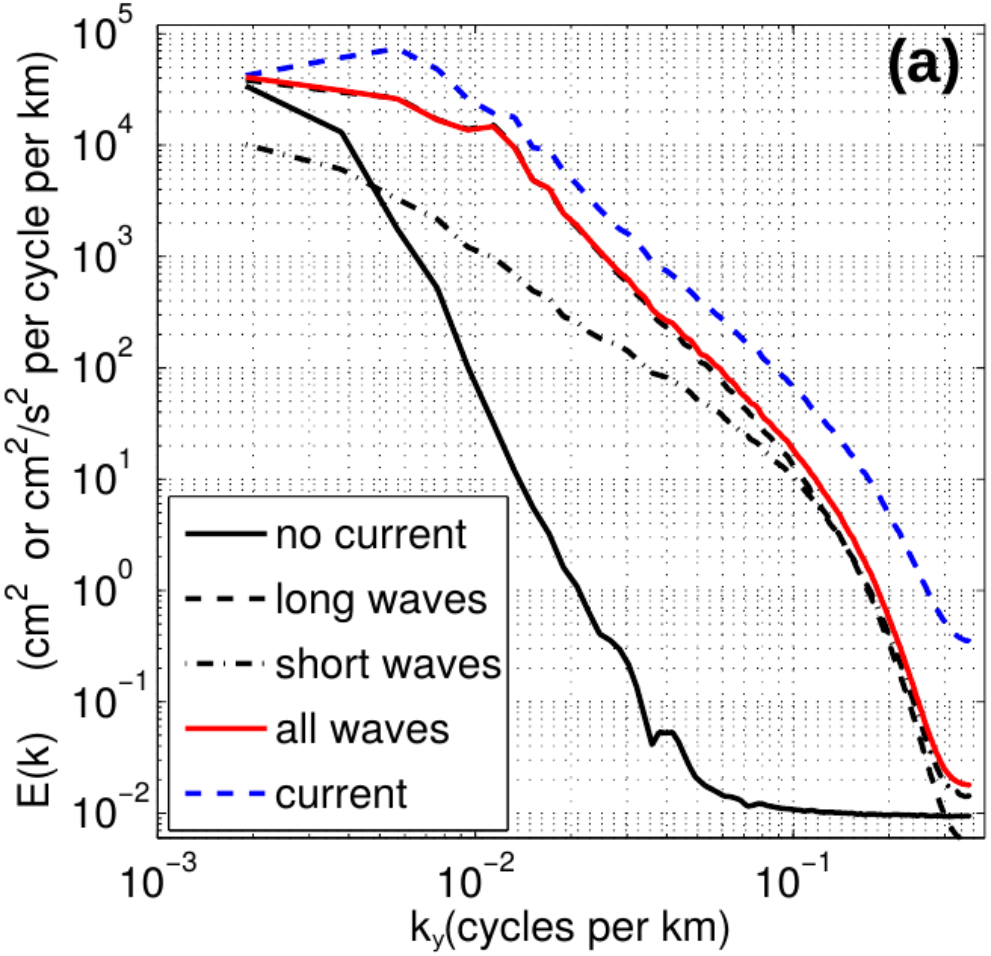


Hs spectrum follow current : $k^{-2.5}$
→ note that short waves (T < 6 s) roll off slower

If the Hs error is 10 % what is the spectrum of that error?

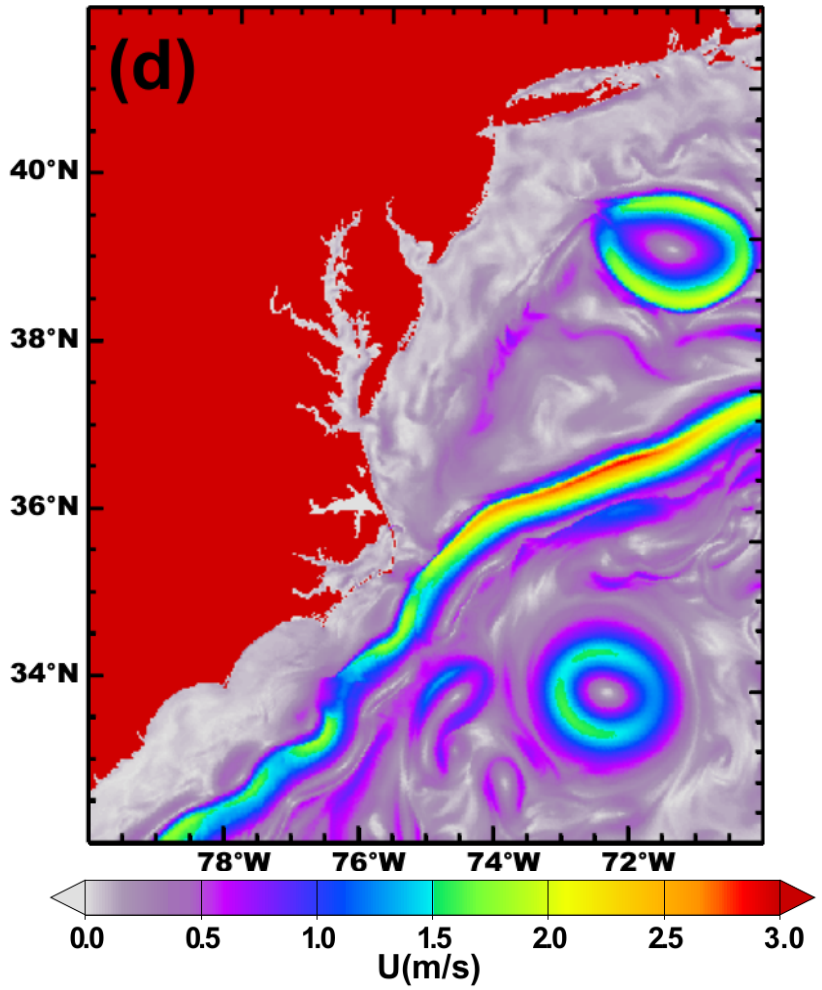
If one value for full swath
→ error spectrum = Hs spectrum

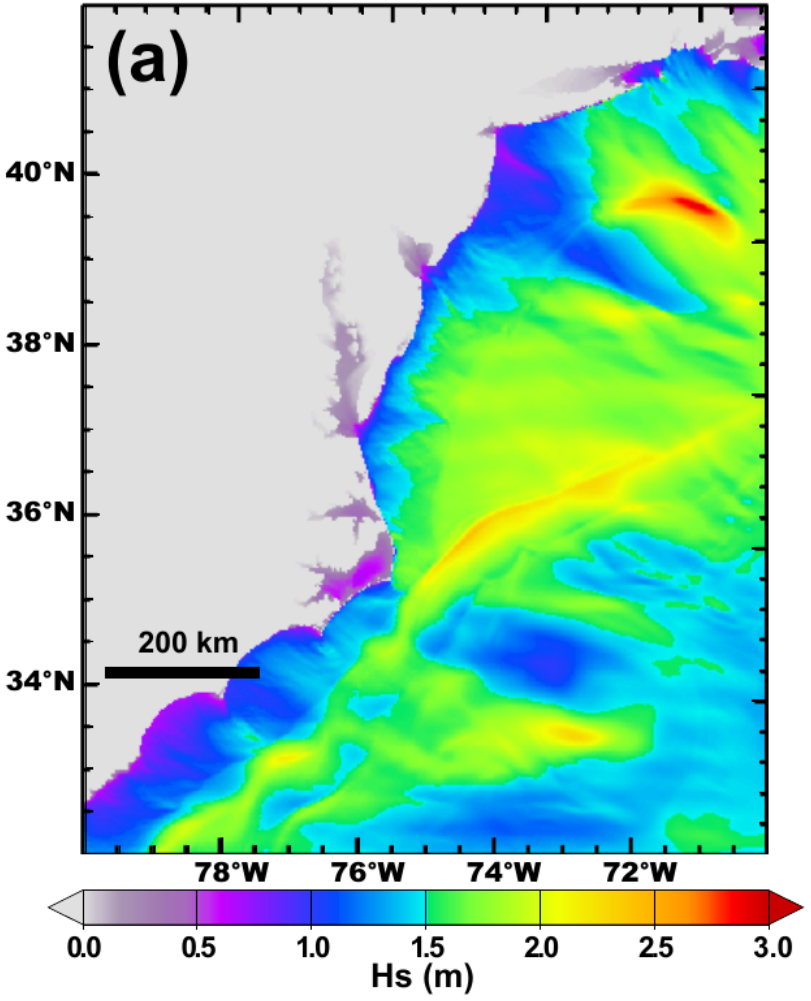
→ error @ 100 km ~ 10 cm² / cy/ km
→ error @ 10 km ~ 0.01 cm² / cy/ km
… OK, Hs > 2 m (Drake passage)

But what about true gradients of current ? Not a *model* ...
→ how many estimates of Hs needed ?

1. Geometric sea state bias
Small scale gradients of Hs

First : how fast does Hs varie spatially ?
What about Hs ~ 2 m ? moving to east coast (ROMS model by J. Gula)





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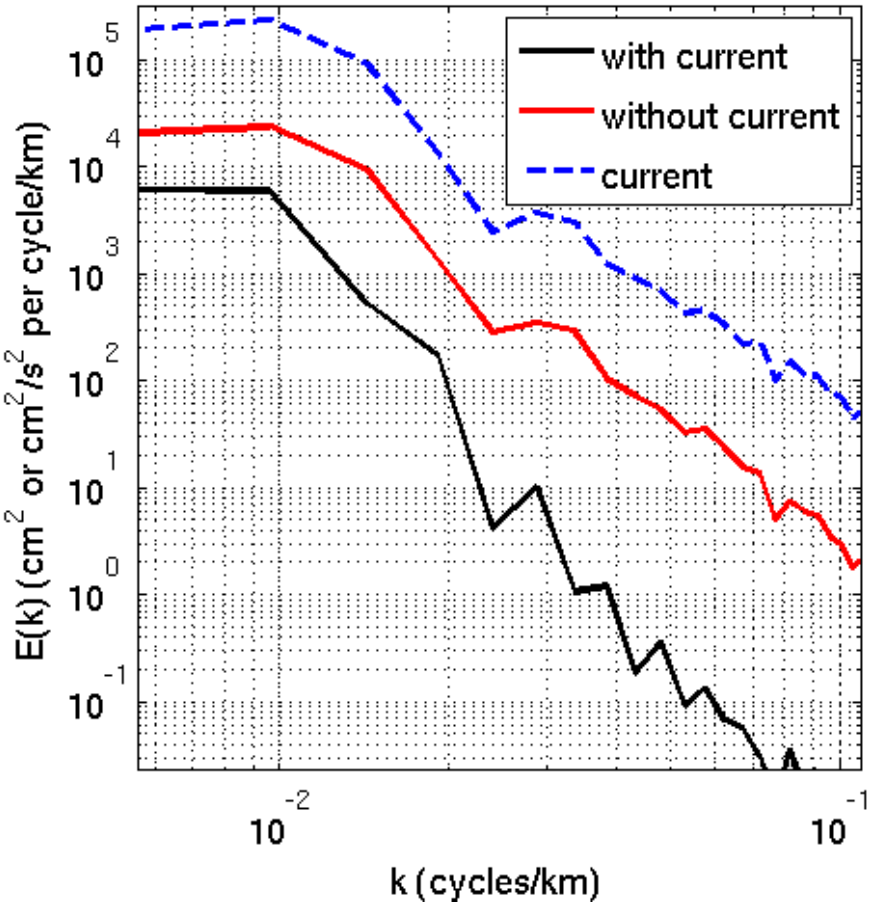
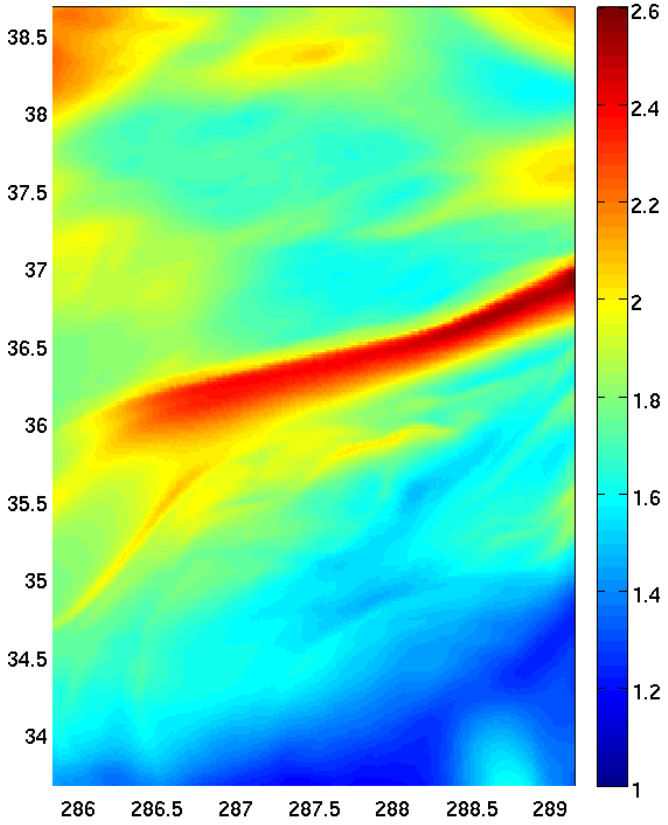




→ **error @ 100 km ~ 20 cm² / cy/ km**

→ **error @ 10 km ~ 0.002 cm² / cy/ km**

1. Geometric sea state bias
Small scale gradients of Hs

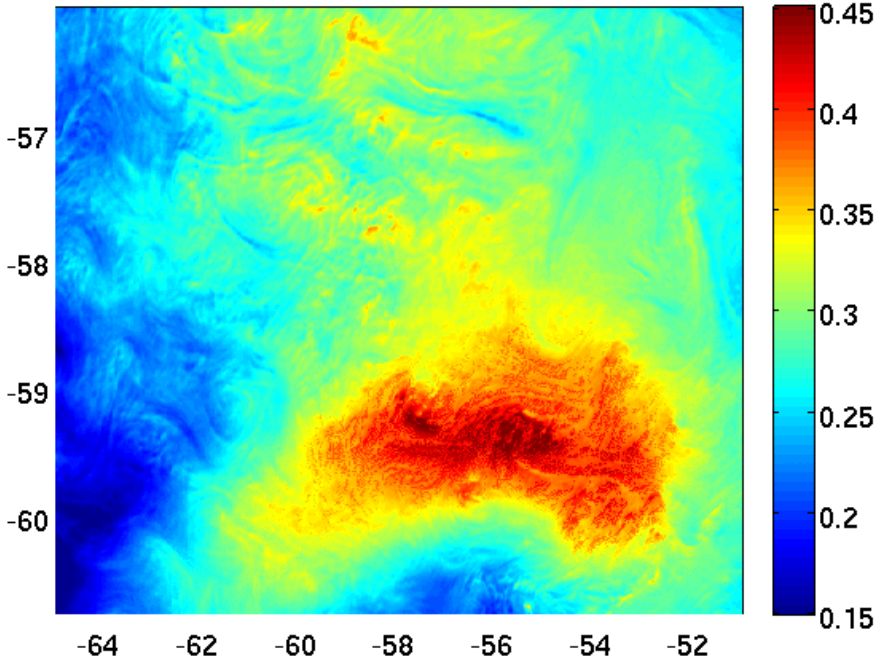
Now, what about **b** ?

- theory for **b** : Longuet-Higgins (1963)

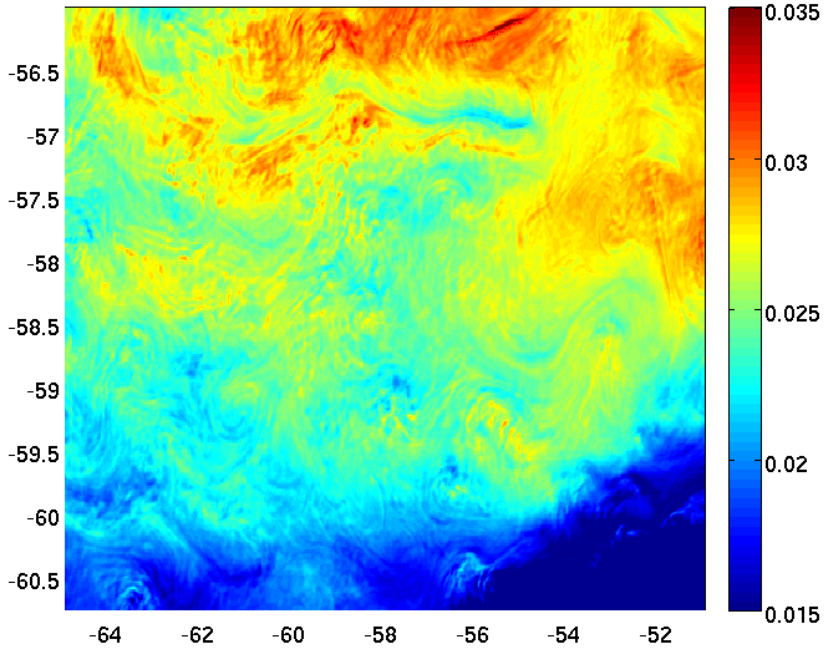
- → 3rd order moments of the wave spectrum
- Measurable proxies :
- - the **surface Stokes drift**
- (related to **Doppler Centroid**)

- the **mean square slope**
(related to **radar backscatter**)

Uss map → spectrum : k^{-2}



mss map → spectrum : $k^{-1.5}$



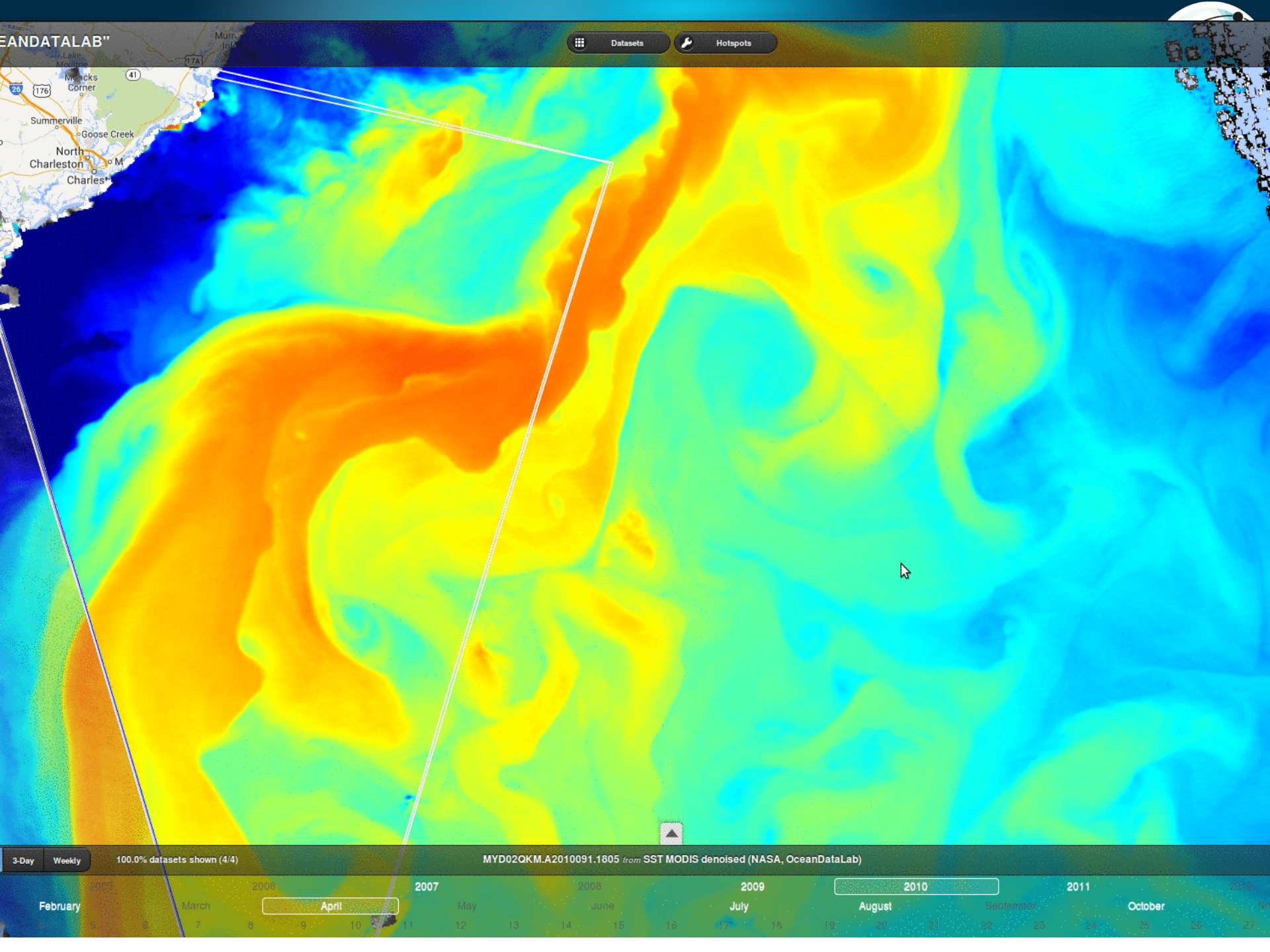
Recommendations for the OBP?
… and others …

1) Small-scale variations in Hs are dominated by currents
   - Not taken into account in SWOT error budget.
   - Seems important around 100 km : resolved by 3 points cross-swath ?
   - How many points of Hs needed cross-swath ?

2) SSB is not just Hs
   - Measurable proxies are probably :
     - cross-sections
     - Doppler centroïds

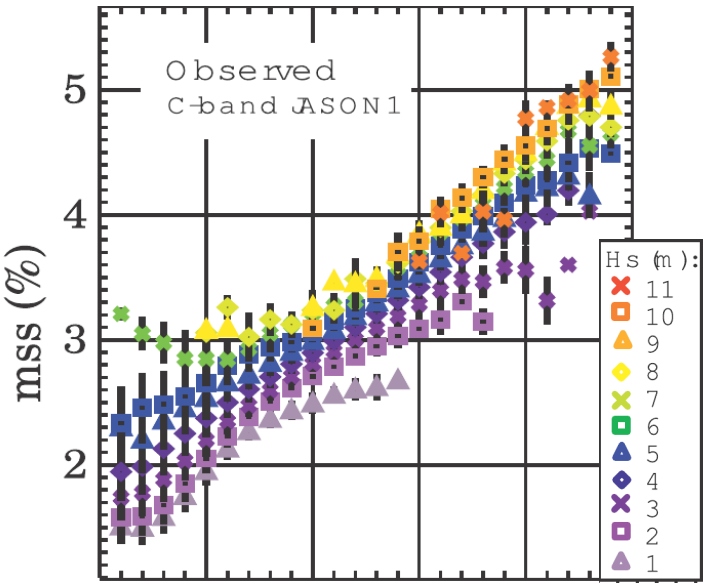
More work to do : use real current gradients→ estimated with glitter
use real waves → drifting buoys

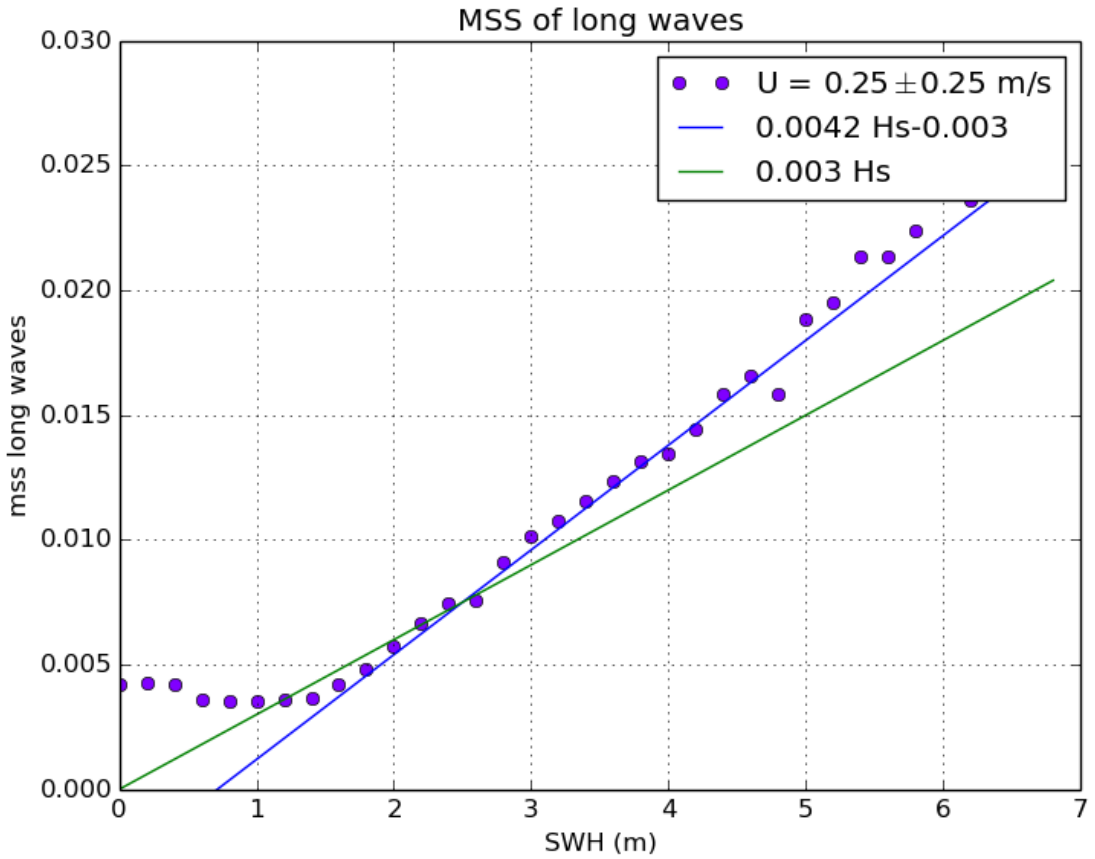
A case for synergistic science
   - Upper ocean mixing (Langmuir ...)
   - (Stokes drift is proportional to Doppler centroid anomaly near-nadir)
   - Wave-current interactions
   - Ice-wave-current interactions …


EANDATALAB"
Datasets
Hotspots
Summerville
Goose Creek
North Charleston
3-Day
Weekly
100.0% datasets shown (4/4)
MYD02QKM.A2010091.1805 from SST MODIS denoised (NASA, OceanDataLab)
2005
2006
2007
2008
2009
2010
2011
February
March
April
May
June
July
August
September
October

EXTRA SLIDES: Hs vs mss_long

Known for C band…. True also for Ka band



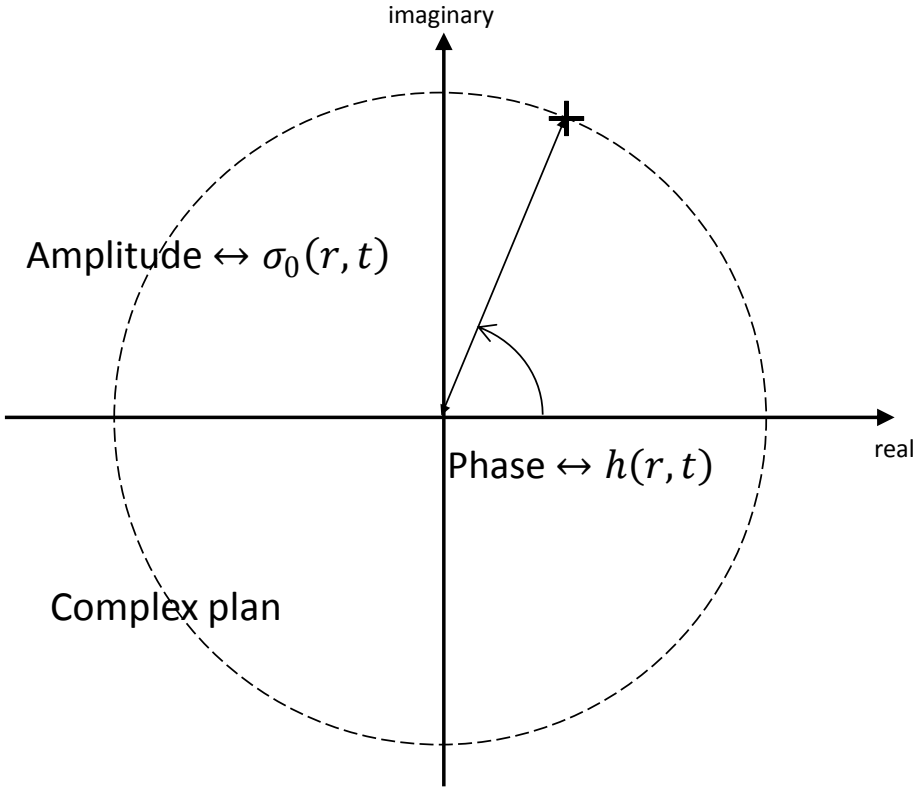


EM Bias for SWOT with the hands

The sea surface being a collection of facets, each one having its own inclination and roughness.

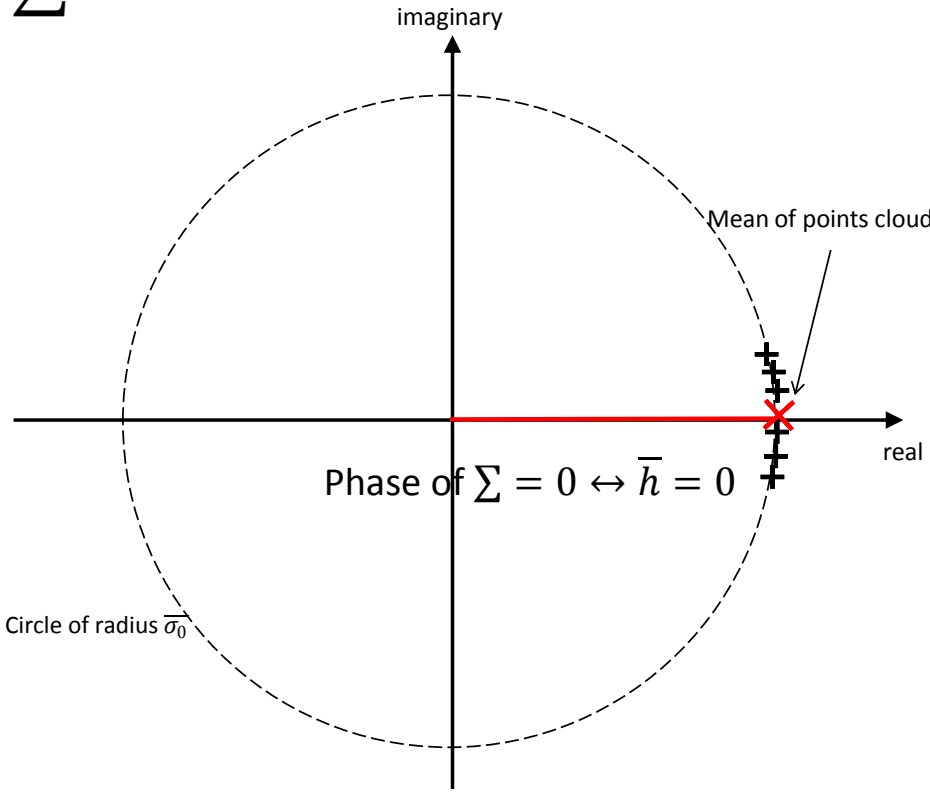
1 weighted facet in the complex plan

$\sigma_0(r,t)\exp[i.\kappa.h(r,t)]$



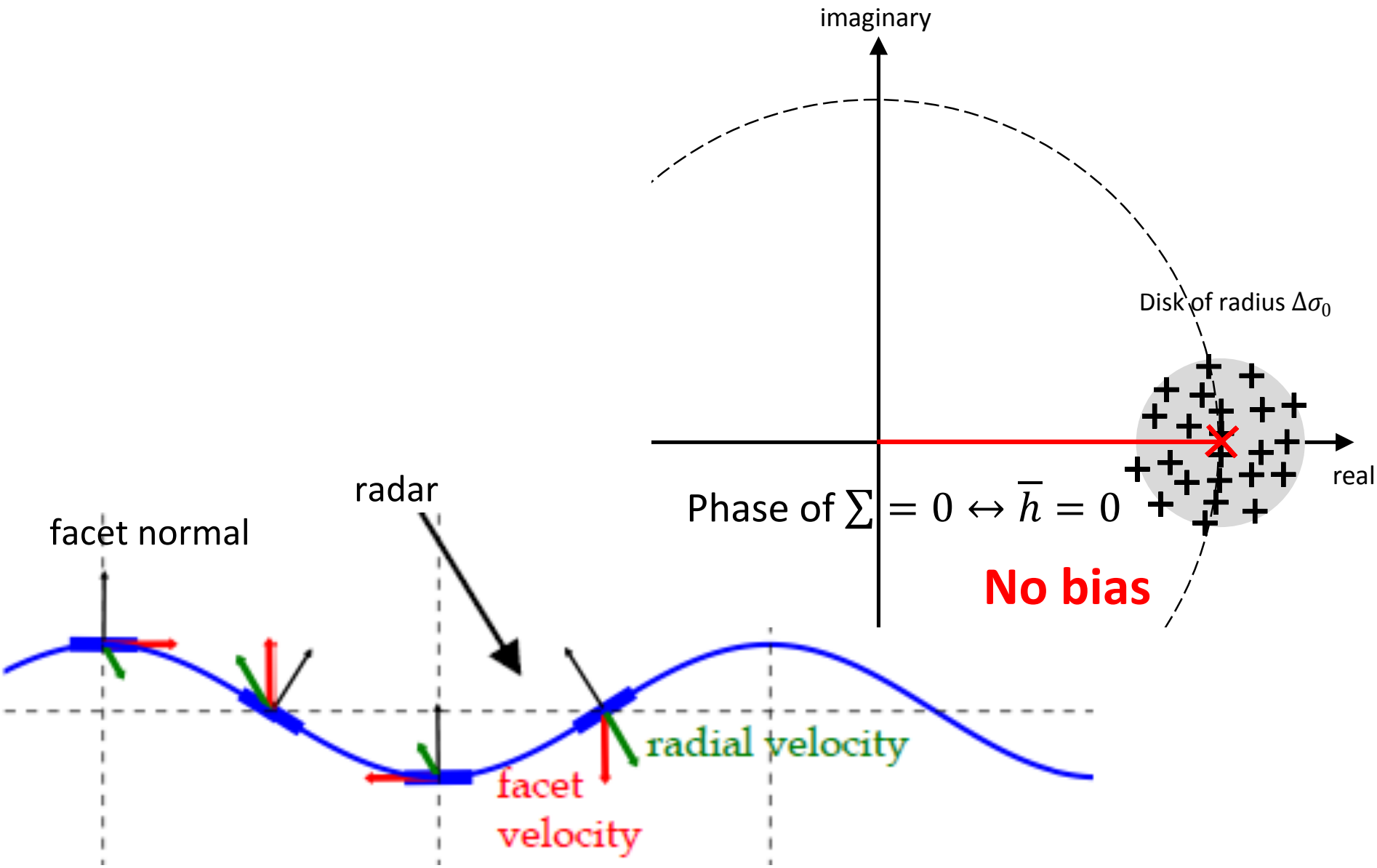
All weighted facets contributing to 1 SWOT pixel

$\sum \sigma_0(r,t)\exp[i.\kappa.h(r,t)]$

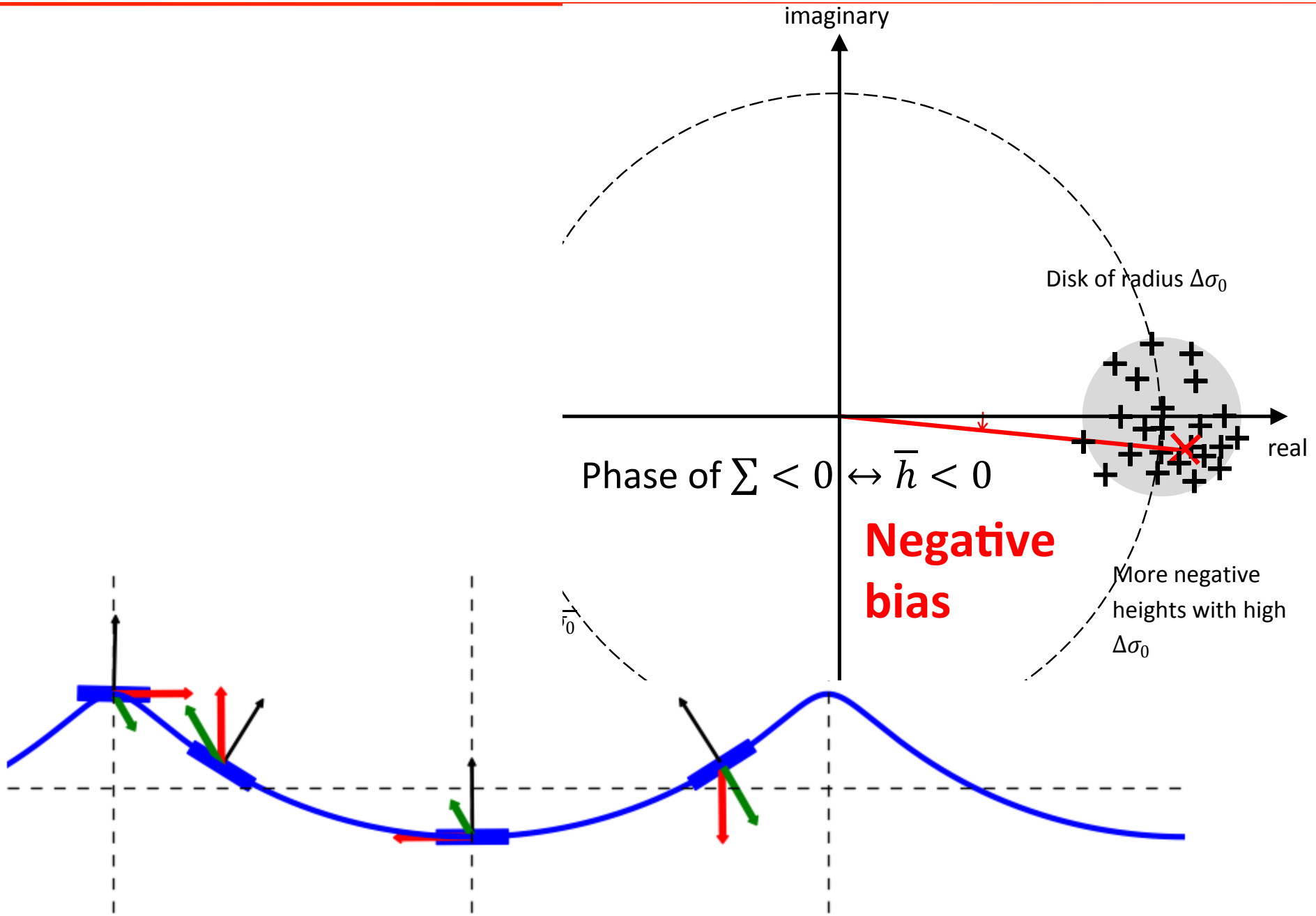


Case 0: Uniform $\sigma_0(r,t) = \overline{\sigma_0}$, $\langle h(r,t)\rangle = 0$

EM Bias for SWOT with the hands: linear/tilt

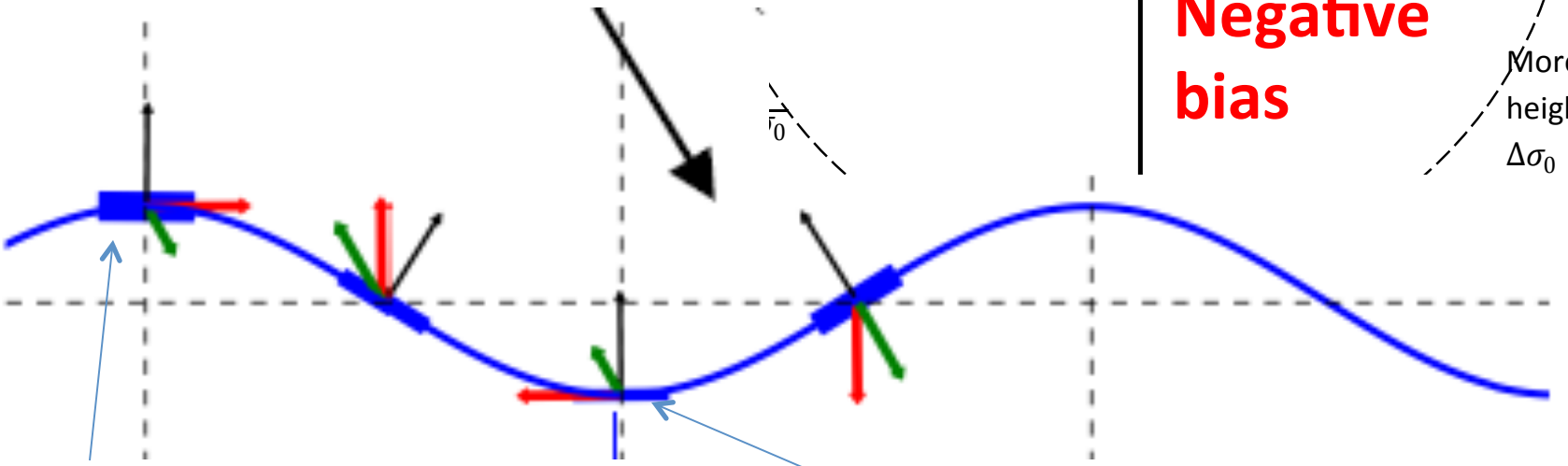


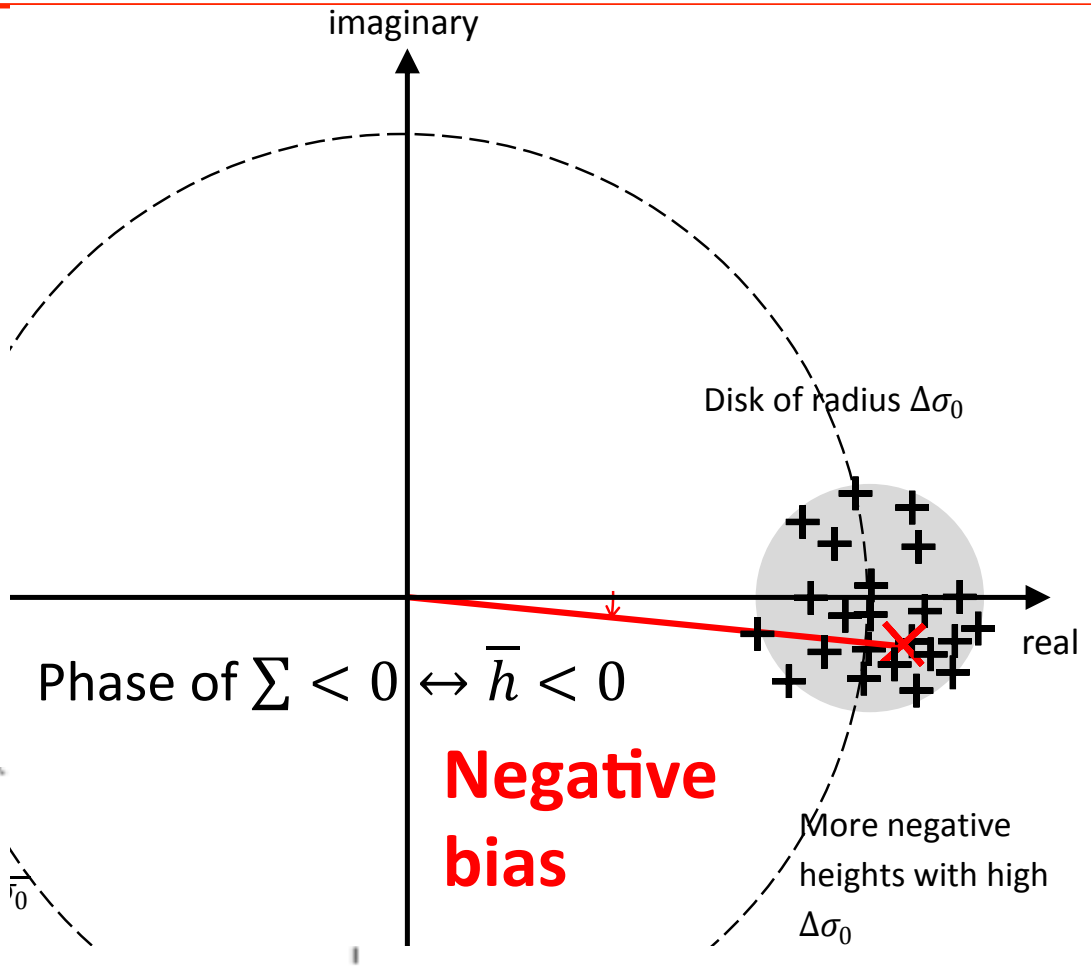
EM Bias for SWOT with the hands: non linear/tilt



EM Bias for SWOT with the hands: linear/roughness mod.

NB, the effects of non-linear waves and roughness modulation are additives.



Strong roughness

Low roughness